GOCE Precise Science Orbits for the entire mission

A. Jäggi[1], H. Bock[1*], U. Meyer[1]

[1] *Astronomical Institute, University of Bern, Switzerland*

[*] *now at PosiTim, Germany*

5th International GOCE User Workshop

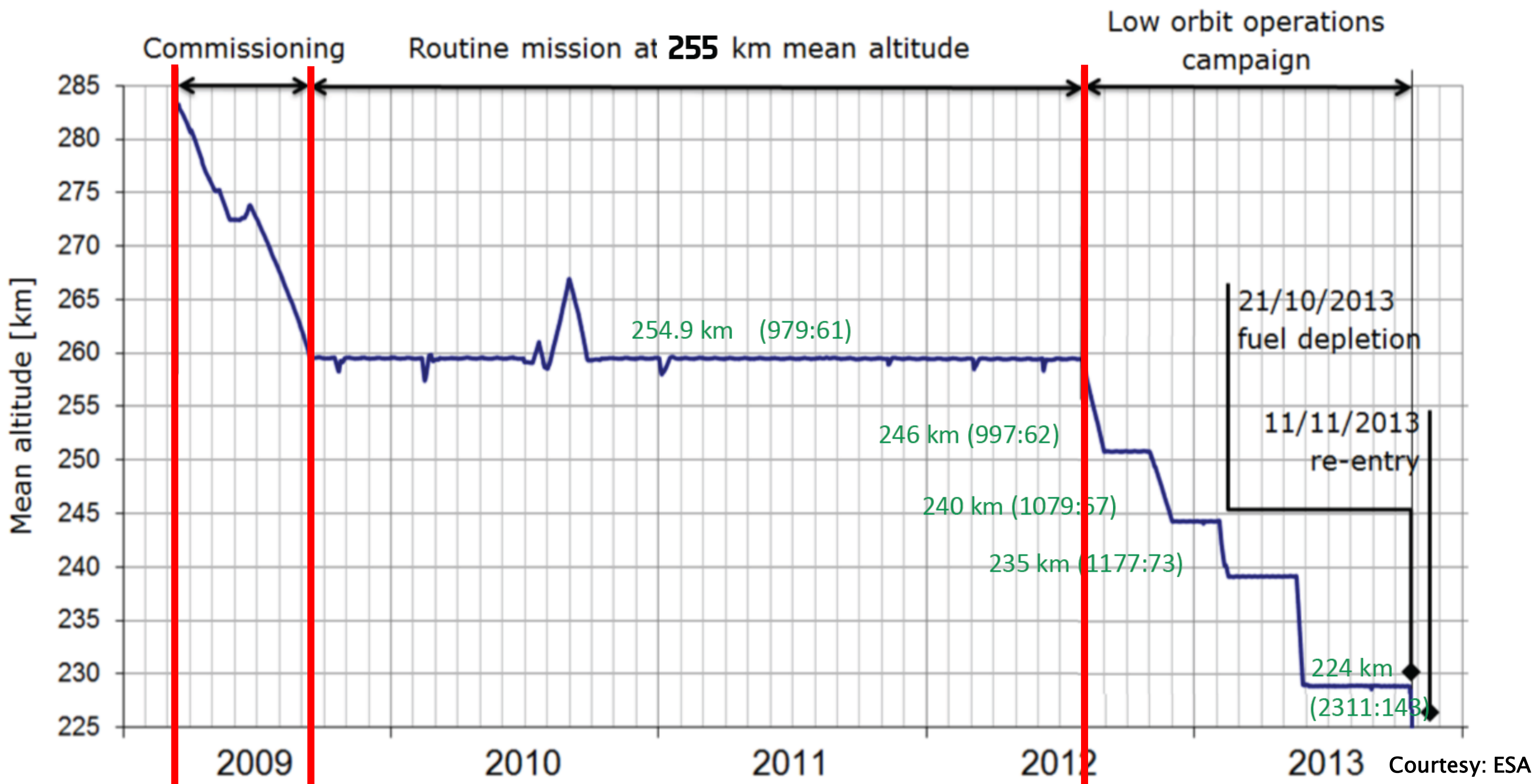
25-28 November 2014

Paris, France

Content

- Precise Science Orbit (PSO) Determination
- Investigation of Systematic Effects
- Orbit Determination for the Final Phase
- Summary

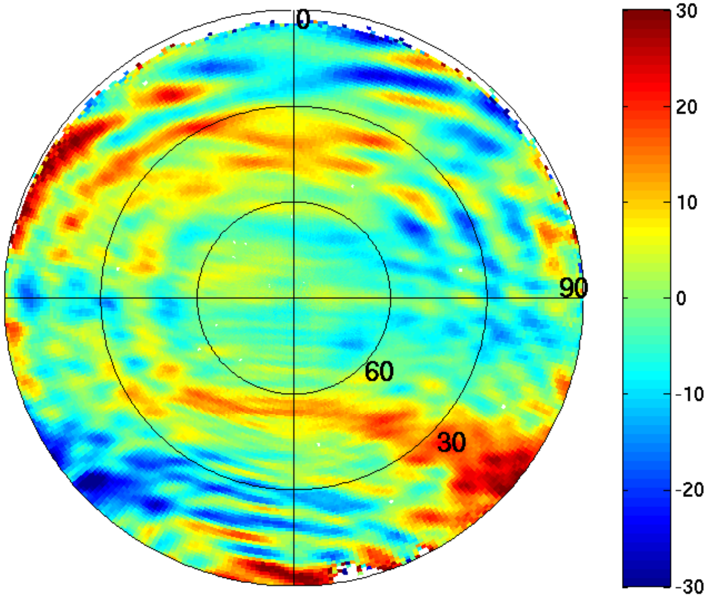
GOCE orbital evolution



- 01/11/2009
- 30/03/2009
- 01/08/2012

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission, 5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

GOCE SSTI

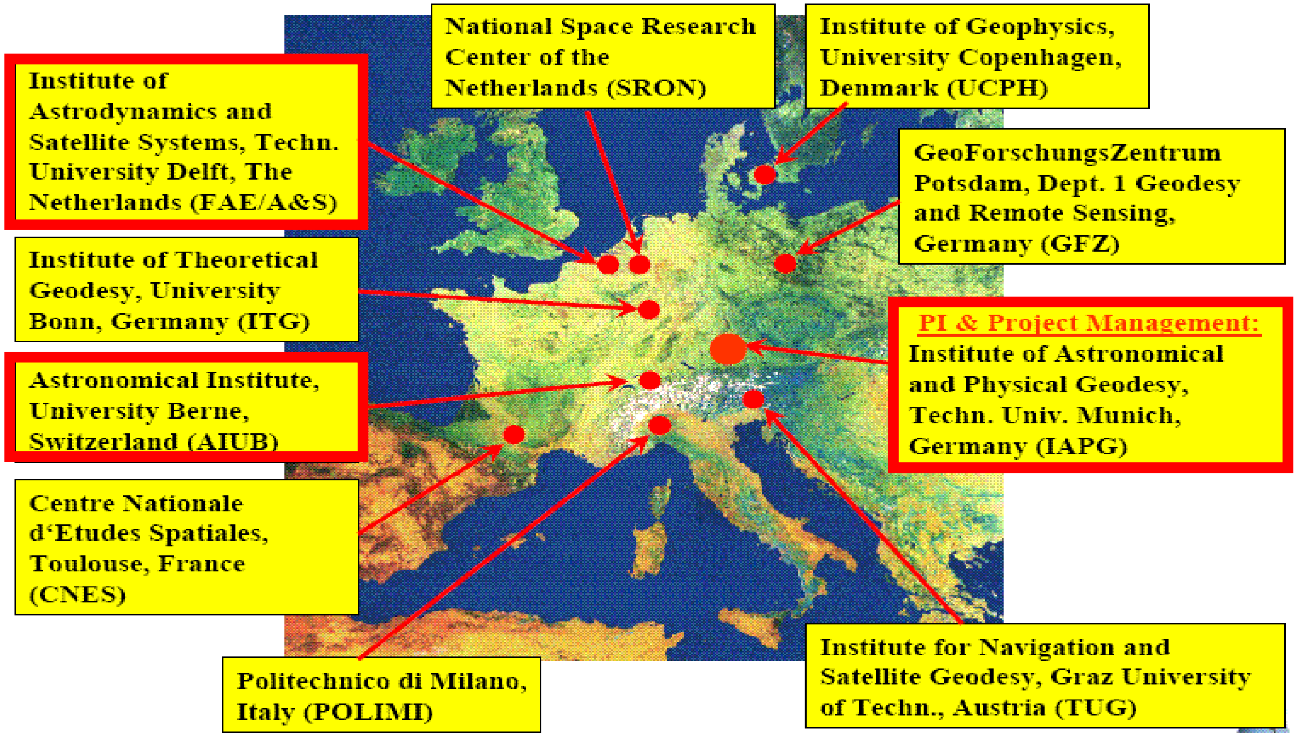


Courtesy: ESA

- Satellite-to-Satellite Tracking Instrument (SSTI)
- Dual-frequency L1, L2
- 12 channel GPS receiver
- 1 Hz data rate
- => Primary instrument for orbit determination
- Antenna phase center variations amount up to ±3cm on ionosphere-free linear combination
- => Mission requirement for precise science orbits: 2 cm (1D RMS)

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

GOCE High-level Processing Facility (HPF)



- **Responsibilities for orbit generation:**
- **DEOS:**

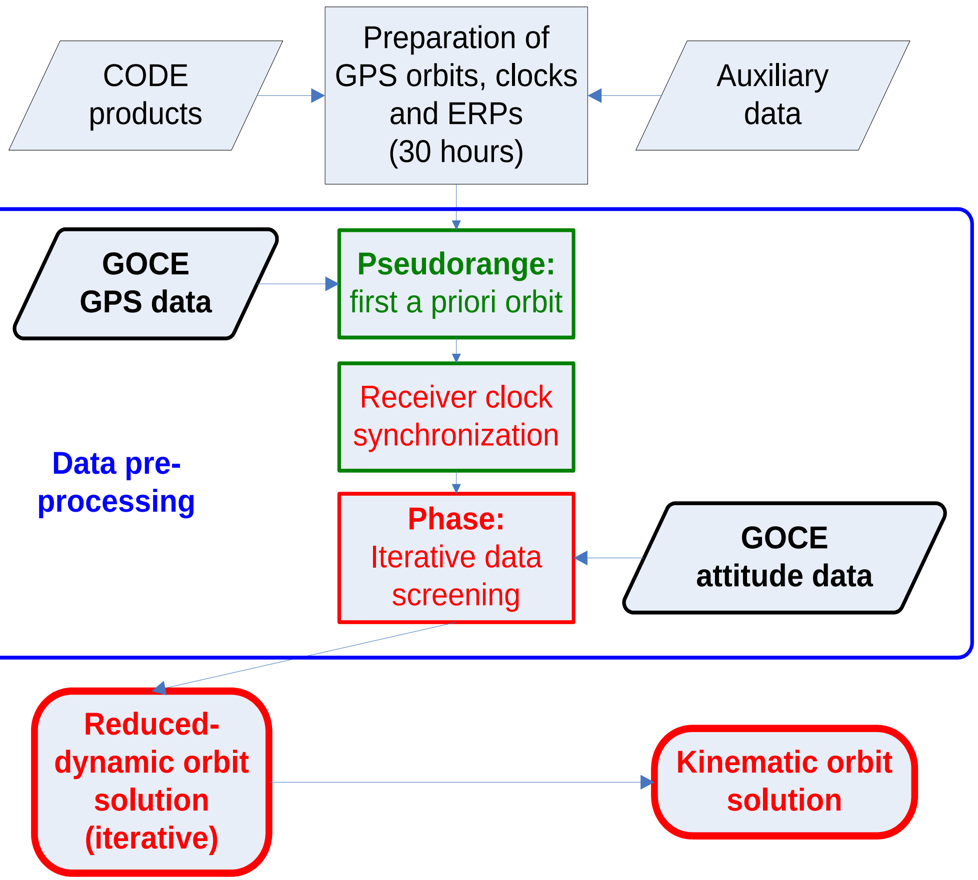
  => RSO (Rapid Science Orbit)
- **AIUB:**

  => PSO (Precise Science Orbit)
- **IAPG:**

  => Validation

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

GOCE PSO procedure



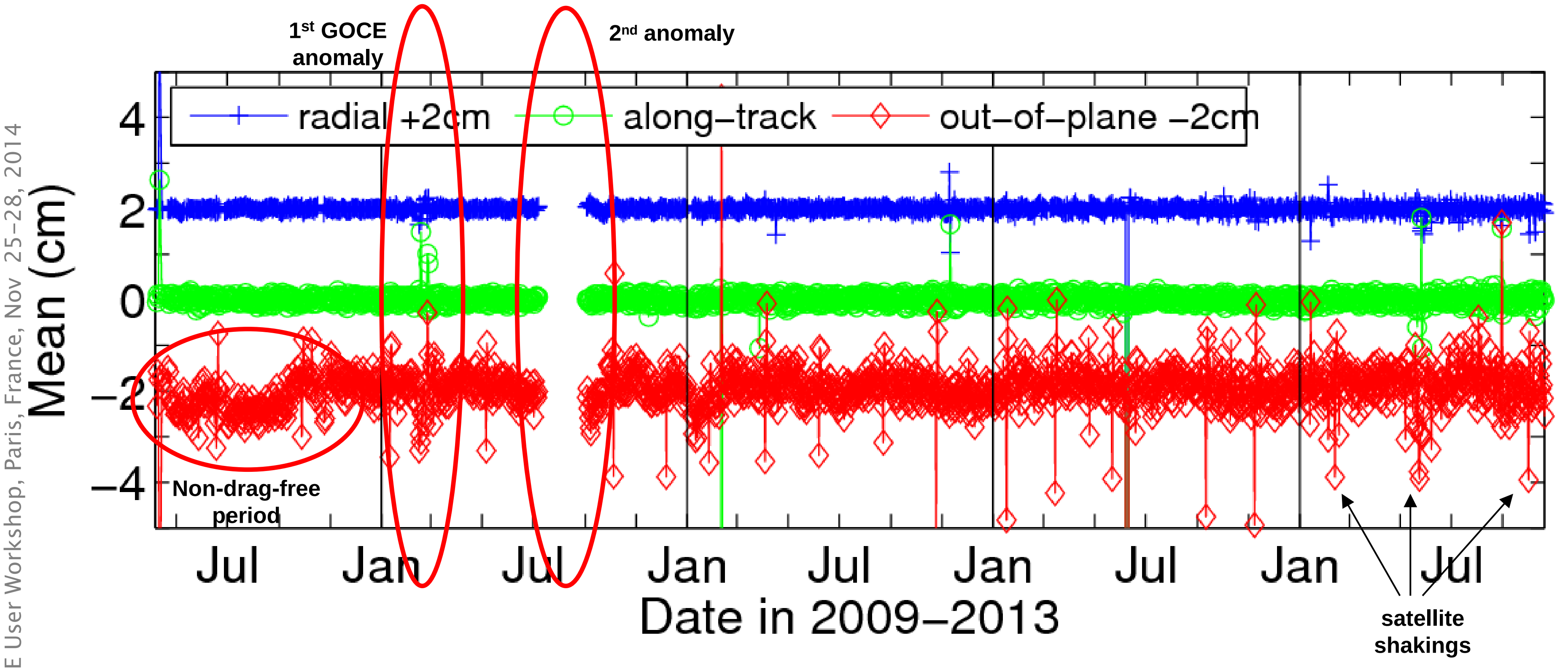
Piece-wise constant accelerations (6 min)

- **Tailored version of Bernese GPS Software used**
- **Undifferenced processing**
- **Automated procedure**
- **30 h batches => overlaps**
- **CODE final products**
- **Reduced-dynamic and kinematic orbit solutions are computed**

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission, 5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

Overlaps of reduced-dynamic PSO solutions

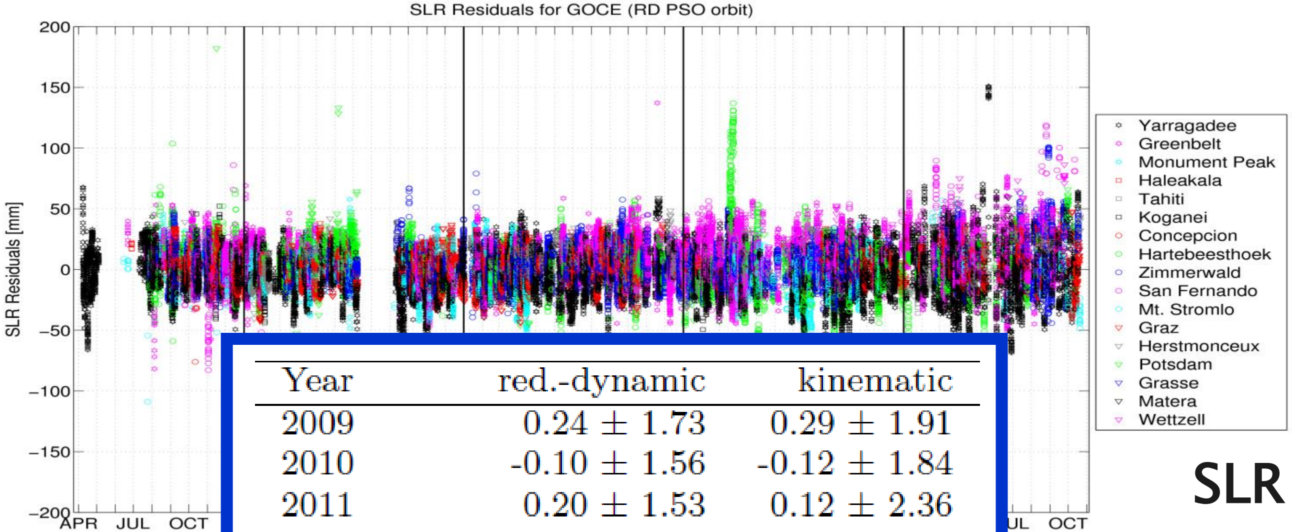
Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25–28, 2014



The results are based on 5h overlaps (21:30–02:30) and reflect the internal consistency of subsequent reduced-dynamic solutions.

The same orbit determination settings were used for the operational PSO computation over the entire mission period.

Orbit validation with SLR

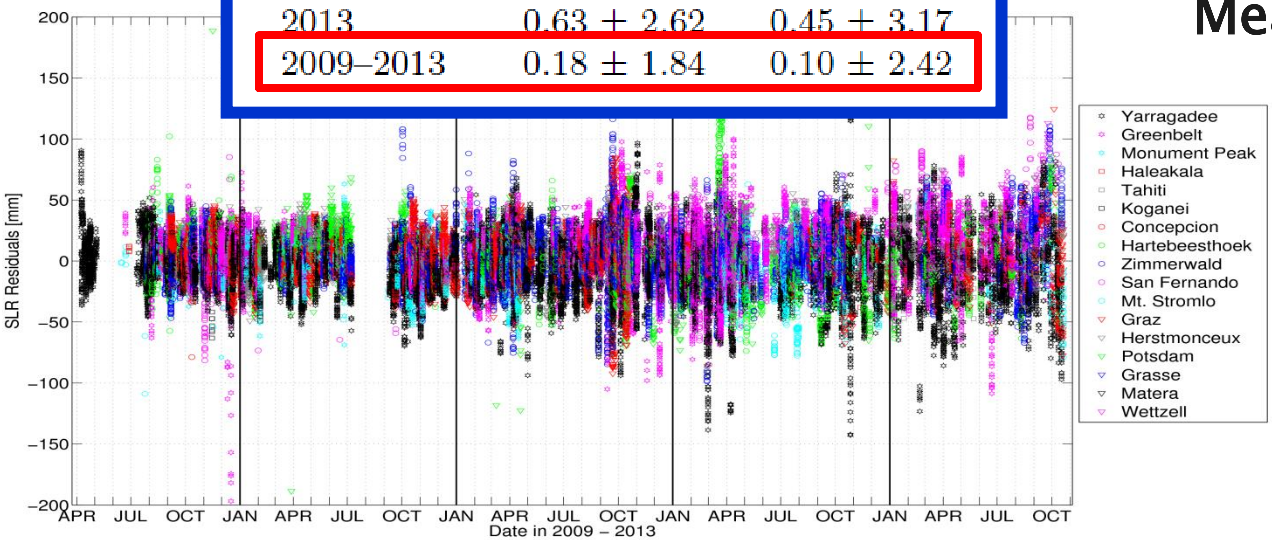


Reduced-dynamic

Year	red.-dynamic	kinematic
2009	0.24 ± 1.73	0.29 ± 1.91
2010	-0.10 ± 1.56	-0.12 ± 1.84
2011	0.20 ± 1.53	0.12 ± 2.36
2012	0.10 ± 1.94	-0.05 ± 2.78
2013	0.63 ± 2.62	0.45 ± 3.17
2009–2013	0.18 ± 1.84	0.10 ± 2.42

SLR statistics:

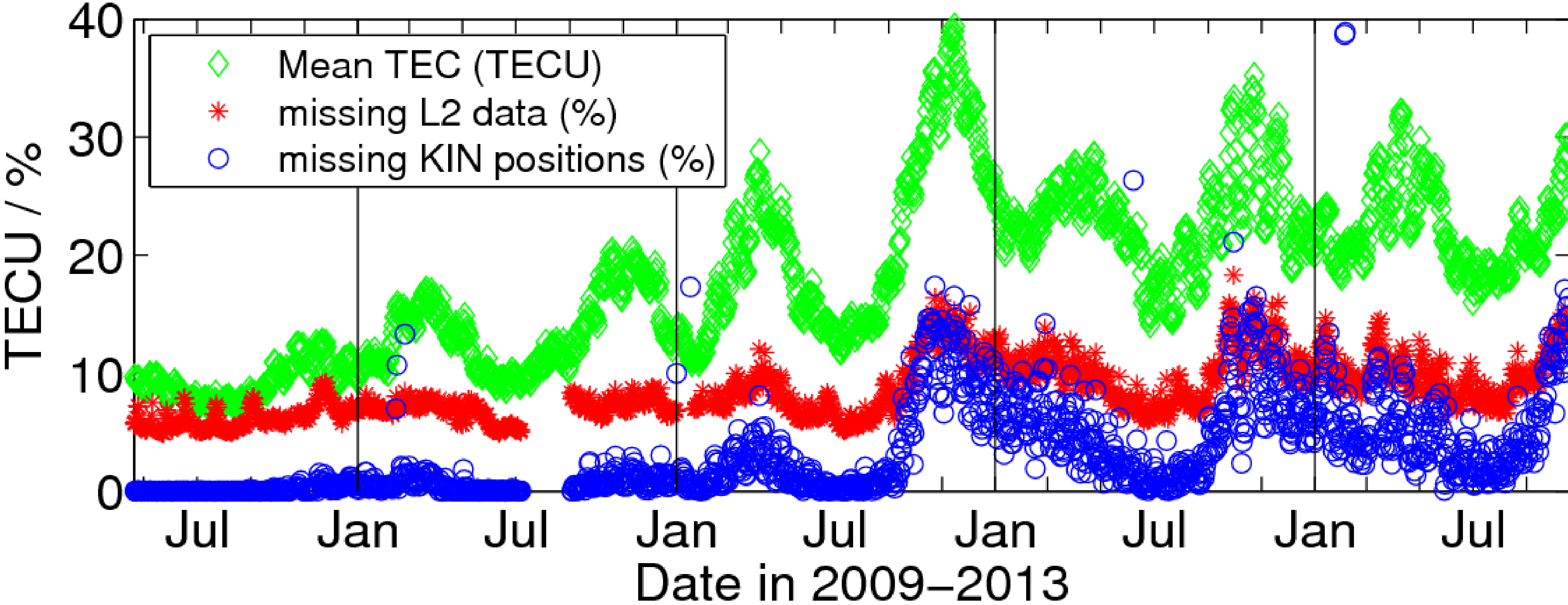
Mean ± RMS (cm)



Kinematic

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25–28, 2014

Differences reduced-dynamic vs. kinematic



The results show the consistency between both orbit-types and mainly reflect the quality of the kinematic orbits.

A high correlation with ionosphere activity and L2 data losses is observed.

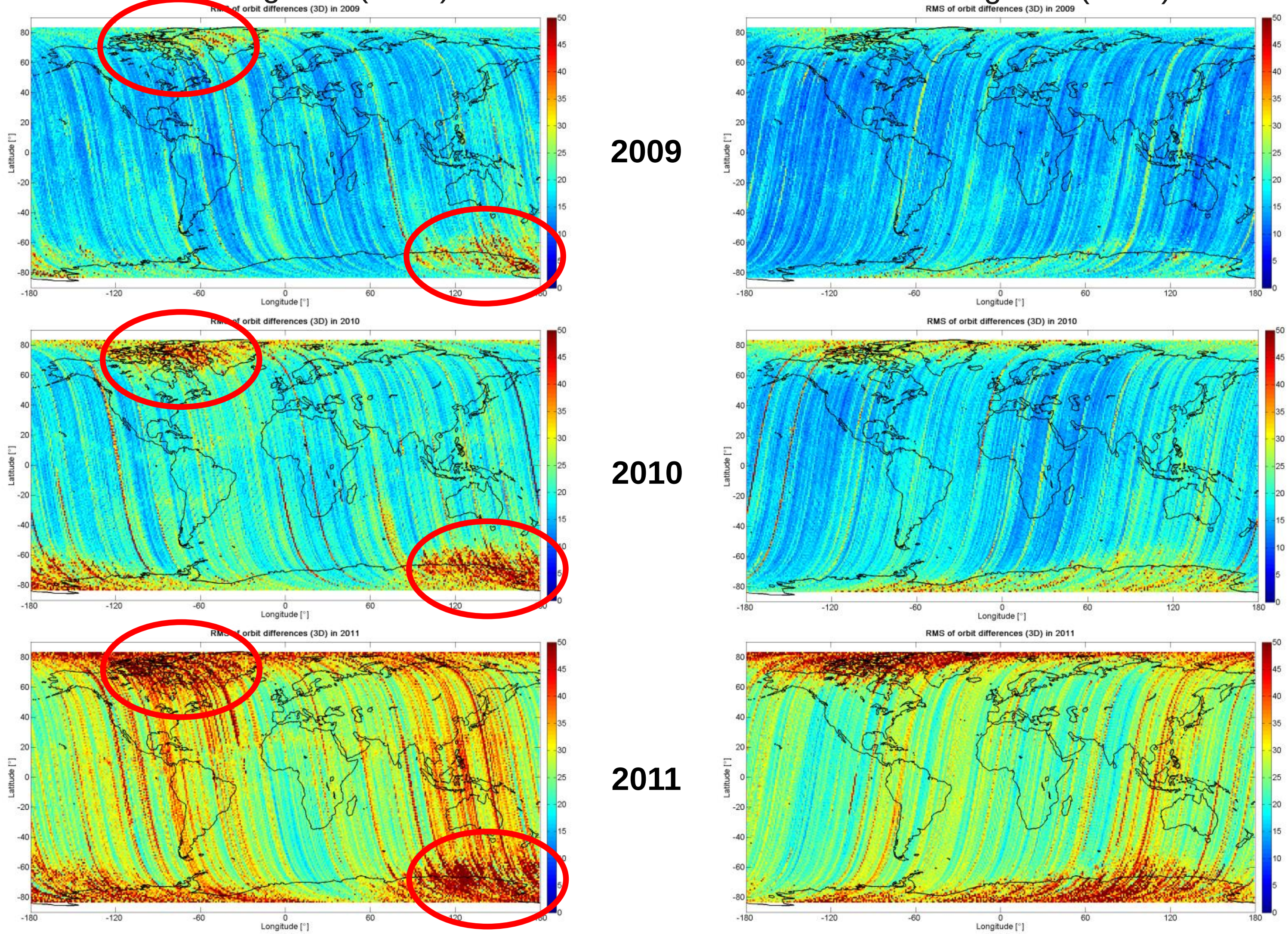
Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission, 5th International GOCE User Workshop, Paris, France, Nov 25–28, 2014

Content

- Precise Science Orbit (PSO) Determination
- **Investigation of Systematic Effects**
- Orbit Determination for the Final Phase
- Summary

Differences reduced-dynamic vs. kinematic

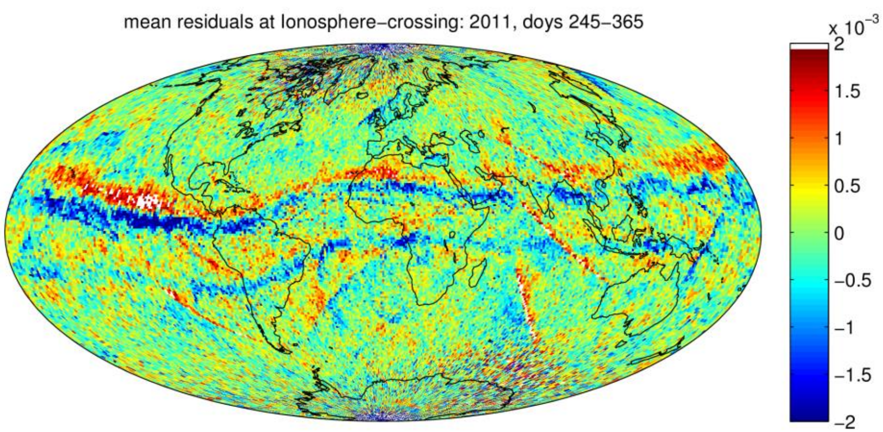
Ascending arcs (RMS) | Descending arcs (RMS)



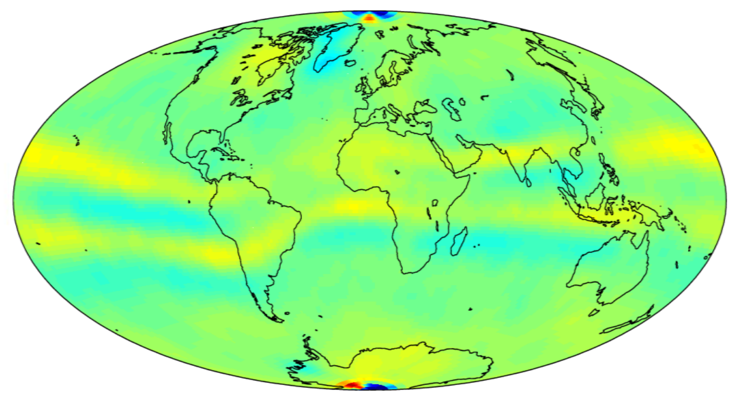
Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25–28, 2014

Systematic effects in the orbits

- Systematic effects around the geomagnetic equator are present in the ionosphere-free GPS phase residuals => affects kinematic positions
- Degradation of kinematic positions around the geomagnetic equator propagates into gravity field solutions (see also poster 77551).



Phase observation residuals (– 2 mm … +2 mm) mapped to the ionosphere piercing point

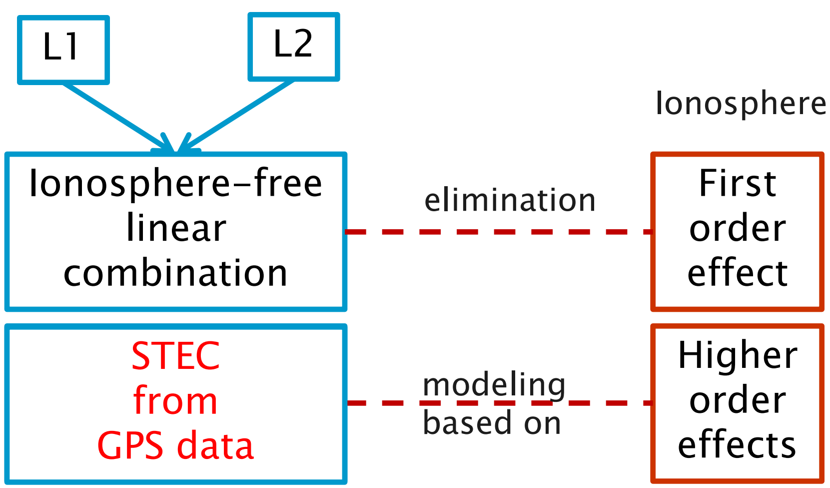


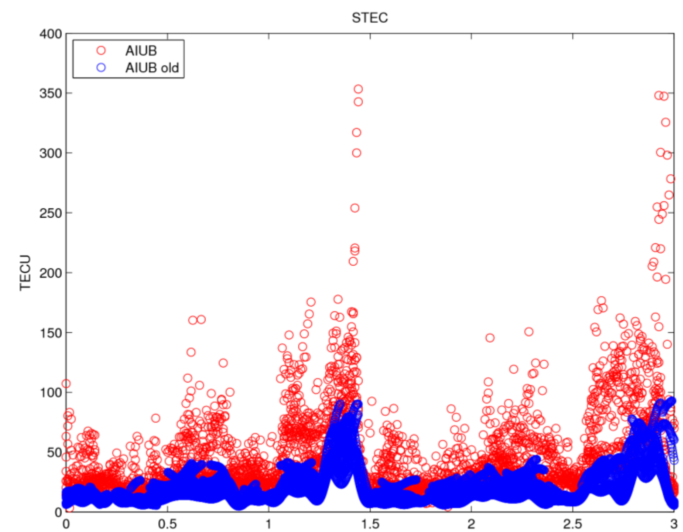
Geoid height differences (–5 cm … 5 cm); TIM-R4 model

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission, 5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

Attempts to model the systematic effects (1)

- Conventional modeling of HOI correction terms does not show any improvements. Also the application of further HOI correction terms than recommended by the IERS Conventions 2010 does not bring any further improvements.
- Ionosphere delays (= slant TEC) need to be directly derived from the geometry-free linear combination to compute more realistic HOI correction terms.

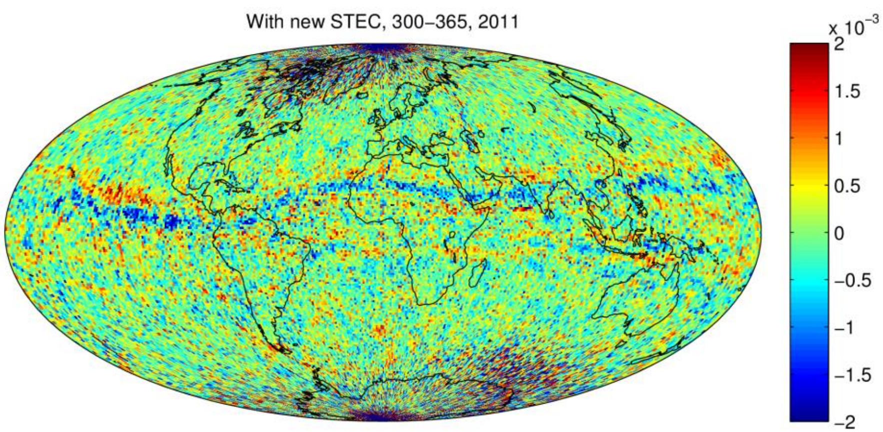




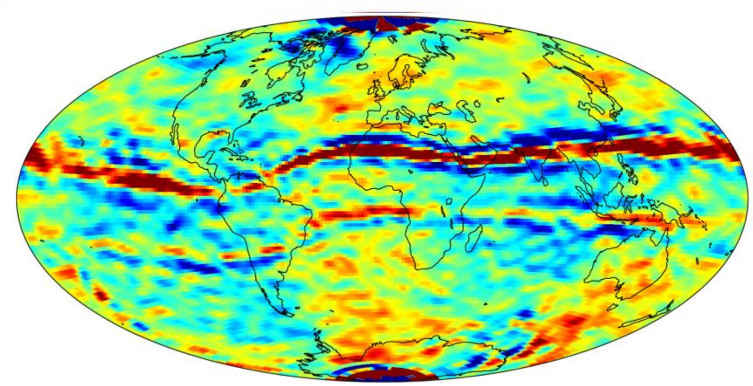
Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

Attempts to model the systematic effects (2)

- STEC estimations are fed into the kinematic orbit determination instead of the global ionosphere map
- HOI correction terms are computed based on the STEC estimations
- Only partial reduction achieved so far in gravity field solutions



Phase observation residuals (– 2 mm … +2 mm) mapped to the ionosphere piercing point



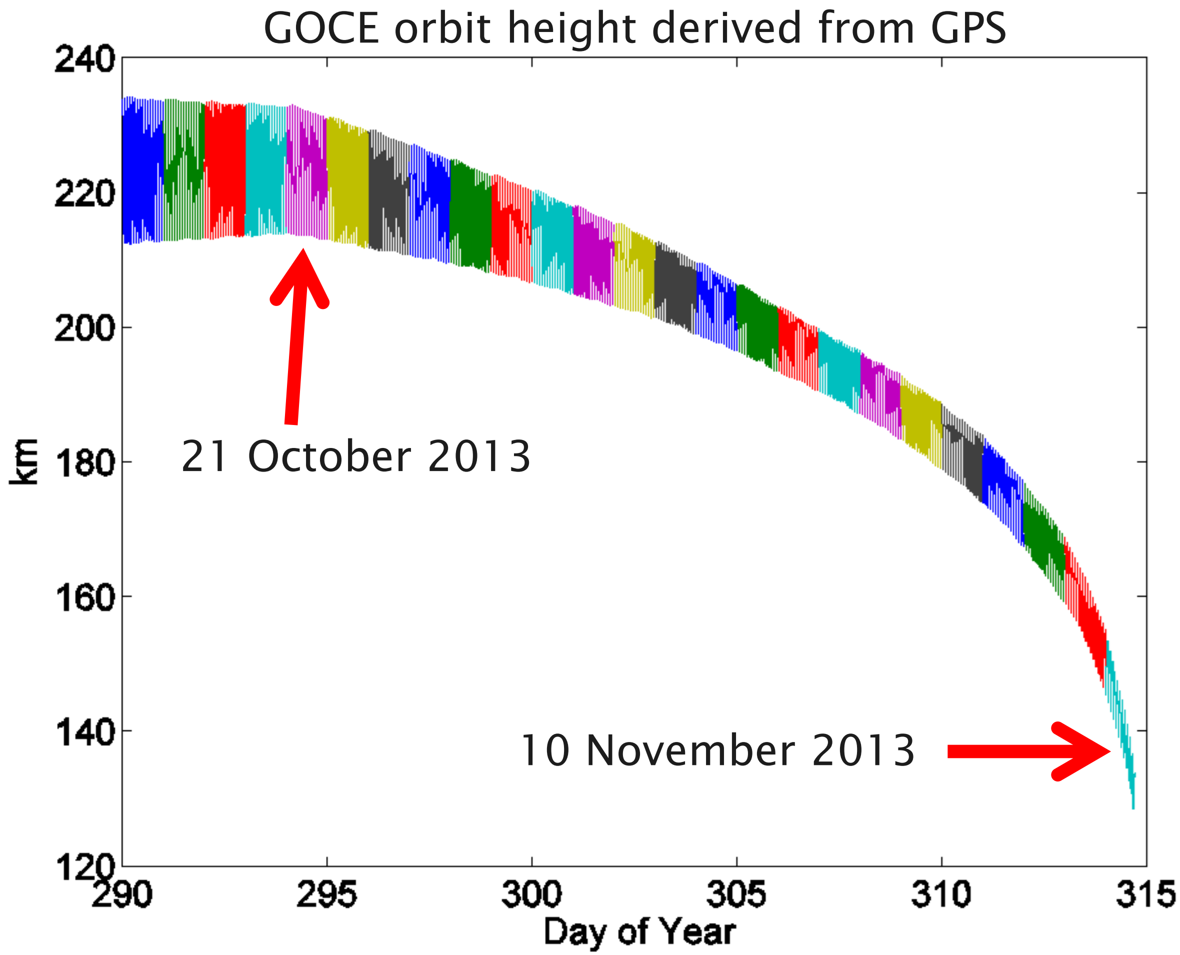
Geoid height differences (−5 cm … 5 cm); Nov–Dec 2011

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission, 5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

Content

- Precise Science Orbit (PSO) Determination
- Investigation of Systematic Effects
- **Orbit Determination for the Final Phase**
- Summary

Background and Motivation

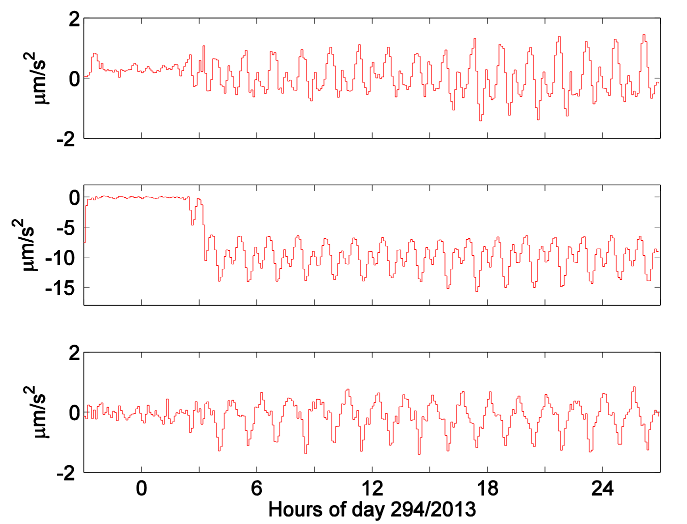


- Last available GPS measurements: **10 November, 17:15:20 UTC**

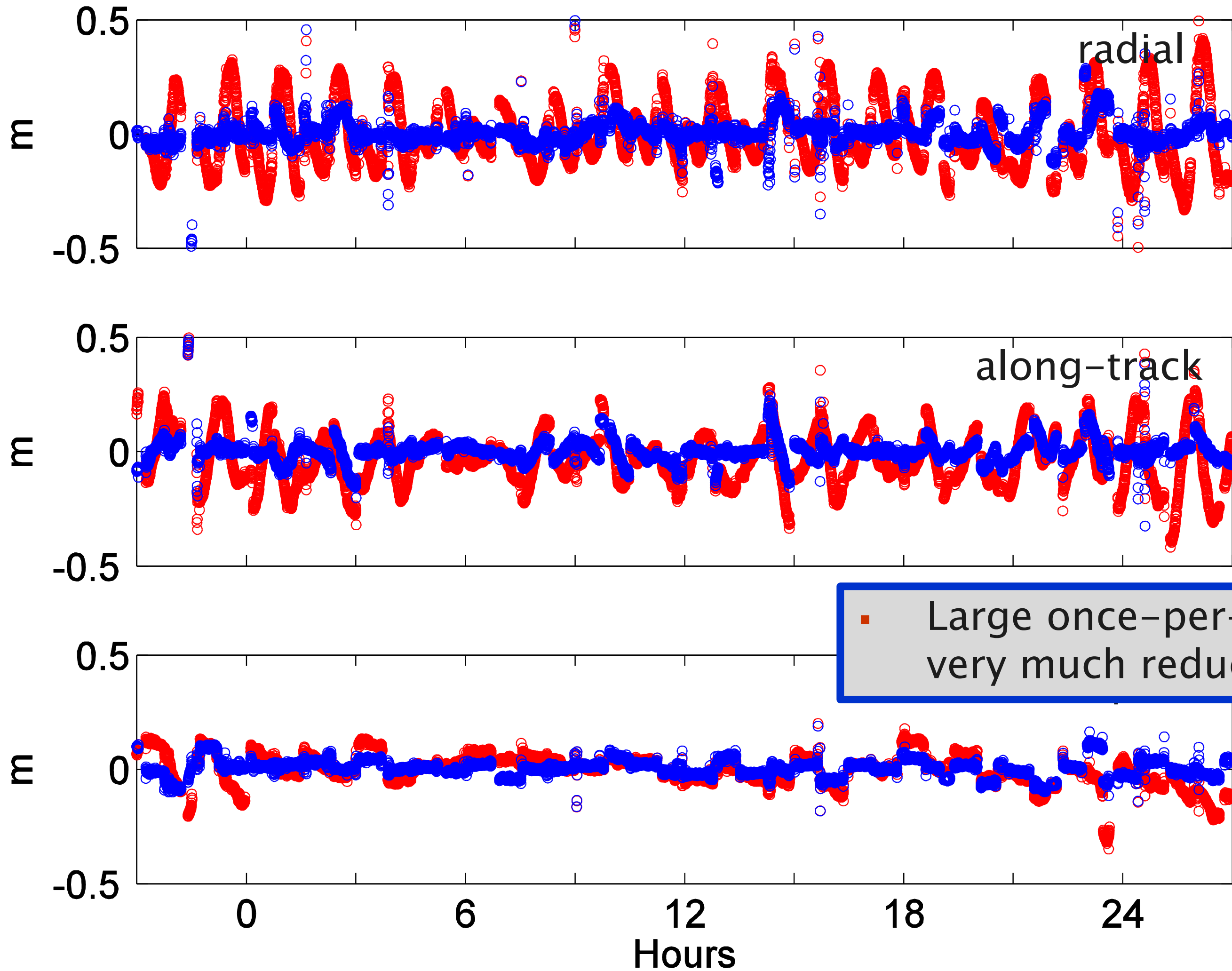
Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

Reduced-dynamic orbit determination

- 30 h processing batches (not for the last 10 days), 10 s sampling, undifferenced processing, ionosphere-free linear combination, CODE Final GNSS orbits and clocks (5 s) and Earth Rotation Parameters
- Orbit models and parameterization:
  - EIGEN5S 120x120, FES2004 50x50 (fixed by GOCE Standards)
  - Six initial orbital elements
  - Three constant accelerations in radial, along-track, out-of-plane
  - 6-min piece-wise constant accelerations in radial, along-track, out-of-plane ($2*10^{-8}$ m/s^2)
- Test solutions with weaker constraints:
  - 2.5 x $2*10^{-8}$ m/s^2
  - 5 x
  - 10 x
  - 25 x
  - 50 x



Differences red.–dyn. ⇔ kinematic orbits

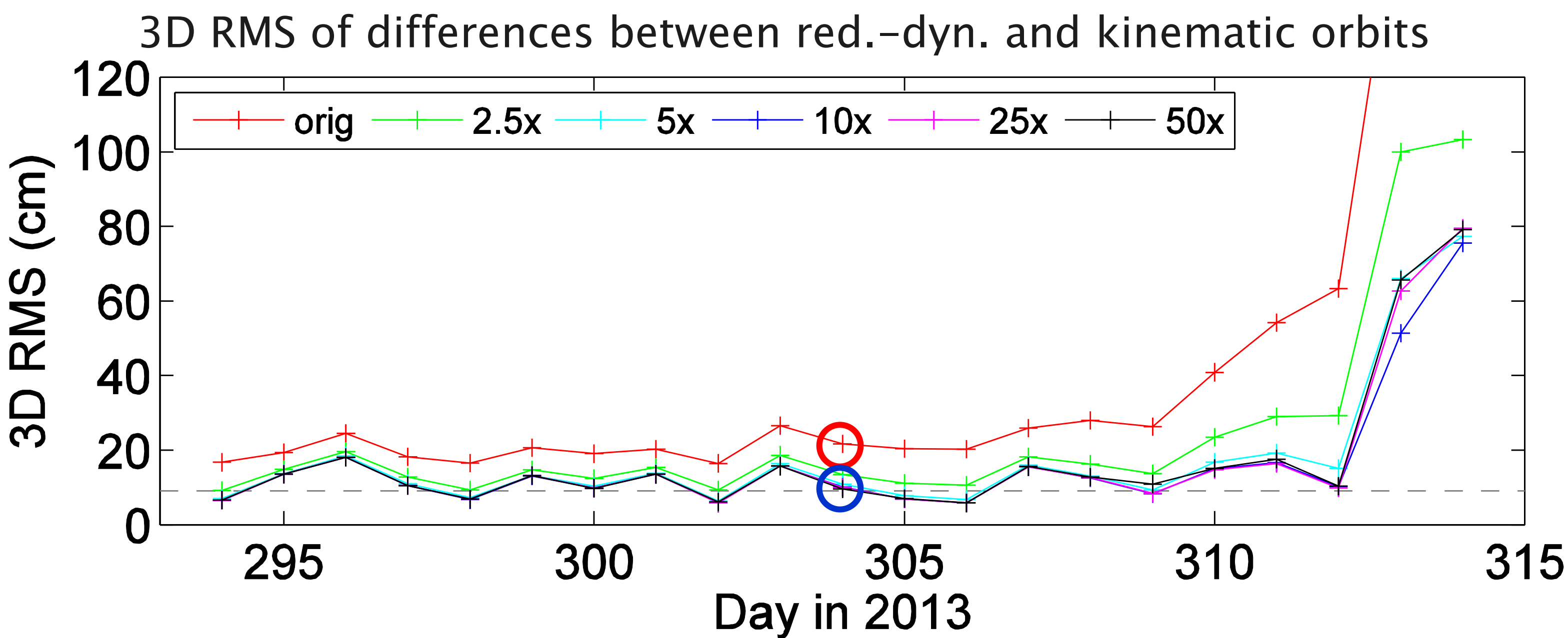


- Large once–per–revolution signal is very much reduced

Original solution and 10x weaker constraints; 31 October 2013

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25–28, 2014

Solutions with weaker constraints



- Test solutions with weaker constraints show better consistency with kinematic orbits.
- Differences between 5x and 50x weaker constraints are marginal.
- Except the very last days, these solutions are acceptable.
- SLR validation is not very helpful because of the very small number of passes

SLR validation RD orbits

2.64 ± 5.52 cm

7.25 ± 7.55 cm

4.76 ± 5.03 cm

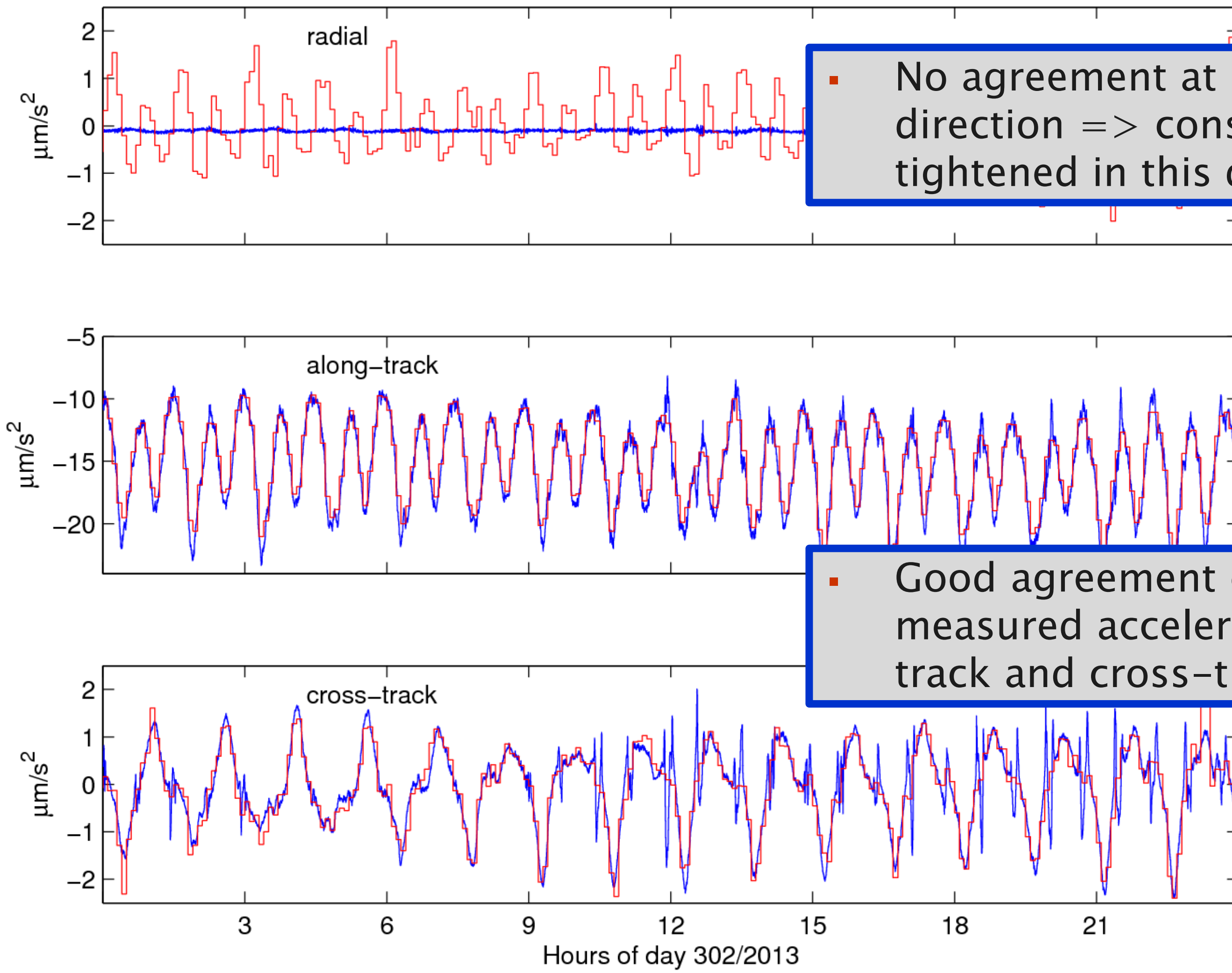
3.78 ± 4.07 cm

3.43 ± 3.73 cm

3.40 ± 3.73 cm

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission, 5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

Comparison with accelerometer data



- No agreement at all in the radial direction => constraints should be tightened in this direction
- Good agreement of estimated and measured accelerations in along-track and cross-track direction

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014

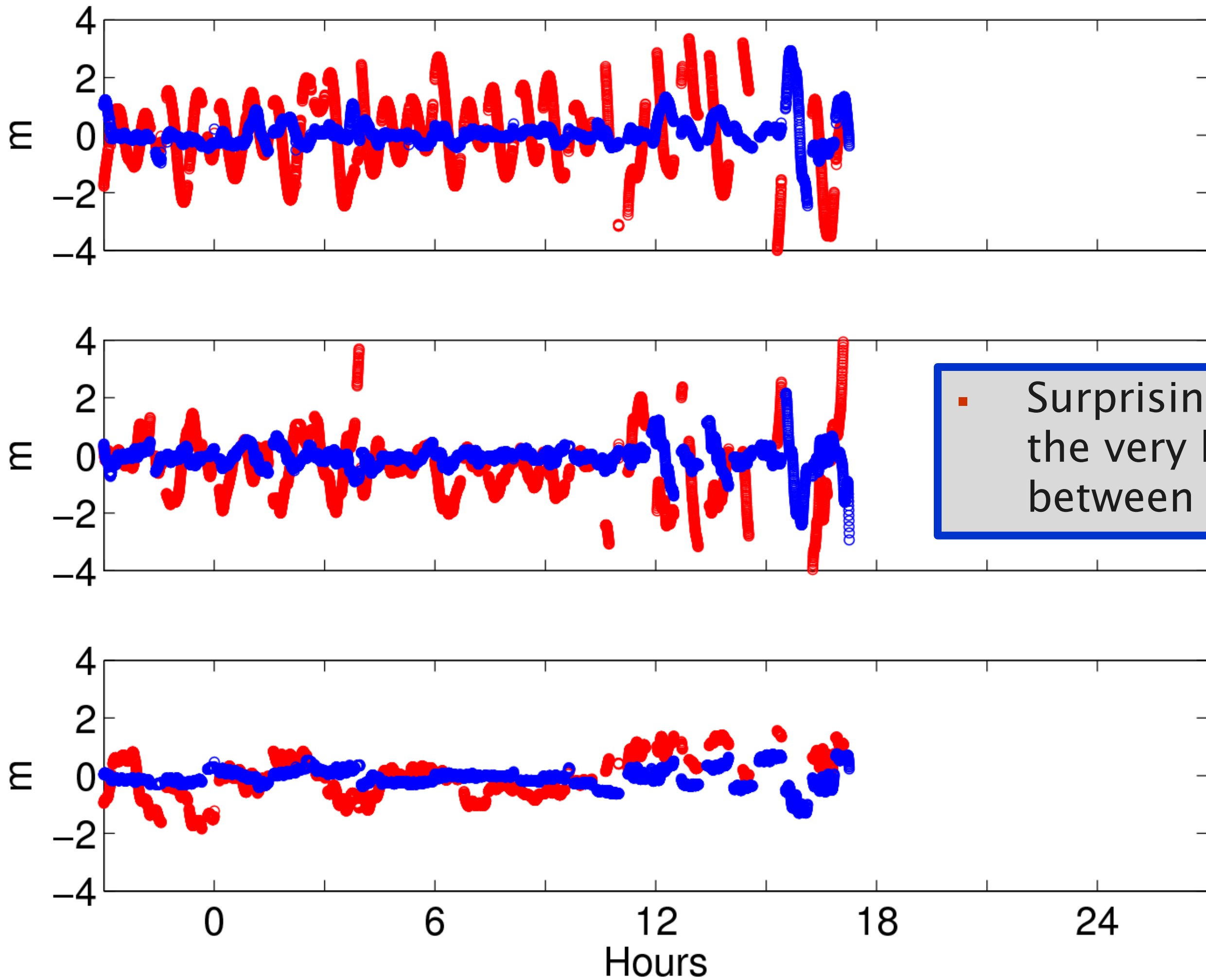
 Astronomical Institute University of Bern

Summary

- Precise Science Orbits are of excellent quality
  - 1.84 cm SLR RMS for reduced-dynamic orbits
  - 2.42 cm SLR RMS for kinematic orbits
- Orbit quality is correlated with ionosphere activity
  - L2 losses over geomagnetic poles
  - Systematic effects around geomagnetic equator
- Final phase orbit determination is challenging
  - Acceptable solutions with 10x weaker constraints (orbits available up to the very last GPS data)

Differences red.-dyn. ⇔ kinematic orbits

Jäggi, A., H. Bock, U. Meyer (2014): GOCE Precise Science Orbits for the entire mission,
5th International GOCE User Workshop, Paris, France, Nov 25-28, 2014



- Surprisingly good agreement at the very last day for altitudes between 130 and 150 km !!

Original solution and 10x weaker constraints; 10 November 2013, the very last day !!